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(54) Title: COMBUSTION OPTIMIZATION WITH INFERENTIAL SENSOR
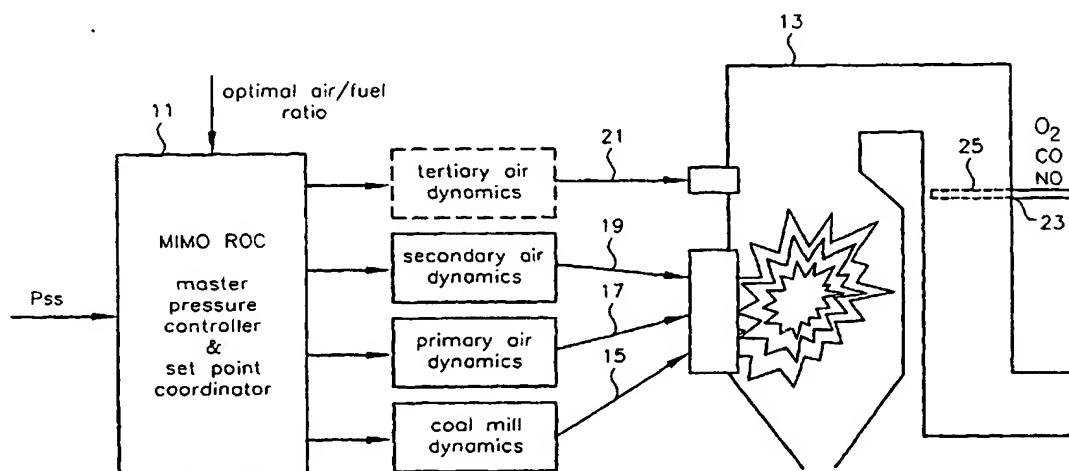
(57) Abstract: A method and system for combustion of fuel in a boiler in which flue gasses are produced. The boiler includes a source of fuel, a source of air, and a controller for controlling the ratio of the source of air and the source of fuel inputted into the boiler. A sensor is used for measuring the concentration of oxygen in the flue gasses. The controller is adapted to calculate the amount of air entering the boiler based on the amount of oxygen in the flue gasses to thereby adjust the air to fuel ratio to include calculated air input and air input from the source of air. A preferred fuel is pulverized. coal. The method and system provide for the air to fuel ratio to be adjusted to optimize efficiency as well as to minimize NO_x production.

COMBUSTION OPTIMIZATION WITH INFERENTIAL SENSOR

FIELD OF THE INVENTION

5   The present invention relates to model-based predictive control technology for boiler control. More particularly the invention relates to the coordination of air and fuel during transients to increase efficiency and minimize the production of NO_x.

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BACKGROUND OF THE INVENTION

The classical approach to combustion air control is to use the measurement of oxygen concentration in flue gas for feedback control of

5 the amount of combustion air. This reactive approach does not guarantee exact air-fuel ration during fast transients. While the standard air-fuel interlock provides acceptable steady-state performance, the solution based on conventional controllers may not be fully satisfactory during the transients, e.g. for boilers operating in cycling regimes, particularly if

10 low-NO_x burning with reduced excess air is used.

Lang U.S. Patent No. 5,367,470 is one of many patents describing the method of analyzing combustion for improved performance, in this case focusing on repetitive adjustment of assumed water concentration

15 in the fuel until actual and calculated values for efficiency reach steady state. Okazaki et al. U.S. Patent No. 5,764,535 uses two-dimensional or three-dimensional cells in a furnace as part of a system employing a gas composition table to simplify the calculation. Carter U.S. Patent No. 5,794,549 employs a plurality of burners to form a fireball to optimize

20 combustion. Likewise, Khesin U.S. Patent No. 5,798,946 converts a fluctuational component of a signal to an extreme point.

Chappell et al. U.S. Patent No. 5,520,123 and Donais et al. U.S. Patent No. 5,626,085 both disclose systems relating to NO_x, using

25 oxygen injection into an afterburner and windbox-to-furnace ratios, respectively. Waltz U.S. Patent No. 5,091,844 and Blumenthal et al. U.S.

Patent No. 5,496,450 both relate to methodology for control relating to sensor feedback. Finally, Stevers et al U.S. Patent No. 5,501,159 teaches the use of a jacketed vessel with multiple chambers and air flows.

5   None of the prior art recognizes the potential for application of model-based predictive control technology for boiler control that will enable tight dynamic coordination of selected controlled variables, particularly the coordination of air and fuel during the transients.

10   It would be of great advantage in the art if predictive control technology could be developed that would take into account relatively fast dynamics of boilers and rate limits imposed by the plant life-time considerations.

15   It would be another great advance in the art if a system could be developed that would focus on power and heat generation to use predictive control technology and rate optimal control to have tight dynamic coordination of selected control variables to result in improved boiler efficiency and reduced NO_x production.

20

          Other advantages will appear hereinafter.

SUMMARY OF THE INVENTION

It has now been discovered that the above and other objects of the present invention may be accomplished in the following manner. Specifically, the present invention employs inferential sensing to estimate the total amount of combustion air for predictive control of air-fuel ratios for pulverized-coal fired boilers and other boiler systems using other fuels. The invention is useful for any fuel burning system, and has been found to be particularly suited for pulverized coal burning boilers.

Using the estimate of the relation between the total air in the boiler rather than just the measured combustion air added to the boiler, the amount of air can be controlled by a predictive controller. The air to fuel ratio is accomplished in fast transients since the system does not have to wait for real-time feedback from analysis of the exhaust gases. The present invention allows the system to use minimum necessary excess air, thus providing low NO_x. production and increased efficiency by at least one percent. The invention contemplates the use of what is termed cautious optimization (cautious optimization is related to the uncertainty in CO and NOx), in which the uncertainty of air entering the system from sources other than directly controlled and measured input is inferentially sensed or estimated from the concentration of O_2 measured in the flue gasses, which represents all of the air in the boiler.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the invention, reference is hereby made to the drawings, in which:

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The FIGURE is a schematic diagram of a master pressure controller with simultaneous air/fuel setpoint coordination in use with a boiler.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The controller system of this invention is based on predictive control technology. Taking into account relatively fast dynamics of boilers and rate limits imposed by the plant life-time considerations, the present invention focuses on power and heat generation applications. The basic idea behind the use of predictive control technology and rate optimal control (ROC) is to enable tight dynamic coordination of selected controlled variables.

A typical application of the MIMO ROC controller 11 for pressure control with simultaneous combustion (air/fuel ratio) optimization is depicted in Fig. 1, where air and fuel are inputted into a boiler 13. In Fig. 1, the fuel (pulverized coal) input 15, and primary air input 17 are controlled by controller 11. In addition to these two essential factors that make up the air to fuel ratio of the boiler, secondary air dynamics input 19 and, when appropriate, tertiary air dynamics input 21 are used as part of the control of the boiler.

Besides the controlled and measured air (the sum of measured primary, secondary and tertiary air are those sources of air around the boiler other than the intentionally introduced air; they represent air that is pulled into the boiler at joints, junctions and other mechanical portions of the boiler. It has been discovered that measurement of the total air in the system is essential for optimum control of the combustion process. While it is not possible or practical to measure air as it is pulled

into the boiler, it is relatively easy to measure the amount of air exiting the boiler in flue 23 as part of the flue gasses. These flue gasses contain quantities of CO and NO_x, as well as O_2, as noted at sensor 25. Controller 11 calculates the total amount of air in the combustion process. From

5   the total air in combustion and the known air input via measured air input 17, 19 and 21, values for additional, or sucked-in air coming in can be calculated.

Based on the data obtained and calculated, the controlled portions

10   of the air to fuel ratio, fuel input 15 and total air 17, 19 and 21 are adjusted to reflect this calculated additional amount of air illustrated at 23 and 25 to optimize the combustion, producing less NO_x and increasing the efficiency of the boiler by significant amounts.

15   In order to demonstrate the efficacy of the present invention, experiments were performed on a commercial boiler. Performance tests were performed on a commercial boiler system using pulverized coal as a fuel, producing superheated steam at a nominal flow of 125 tons per hour.

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Presented below in Tables I and II are the results of test before and after the present invention was implemented. The constants were the boiler itself, the fuel as pulverized coal (adjusted for moisture content) from commercial sources, and the control equipment used to

25   adjust the air to fuel ratio. The variable was the use of a sensor to determine oxygen excess in the flue gas, which in turn was used by the

control equipment to adjust the air to fuel ratio to include all air rather than input air.

Table I

Boiler Performance NO_x Production

Prior Art Using Measured Air	Invention Using Estimated Total Air
maximum at 340 mg/m^3	maximum at 280 mg/m^3
range 200 to 500 (mg/m^3)	range 150 to 50 (mg/m^3)

Thus, NO_x production was reduced by almost 20%, from average values of 340 mg/m^3 to 280 mg/m.

Table II

Boiler Performance Efficiency

Prior Art Using Input Air	Invention Using Total Air
88.1% maximum	88.8% maximum
87-89% range	88-89.5% range

An improvement of nearly 1% efficiency results in substantial economic savings, and is particularly important when combined with reduced pollutants as shown above.

While particular embodiments of the present invention have been illustrated and described, it is not intended to limit the invention, except as defined by the following claims.

CLAIMS

1   1.   A method of controlling combustion of fuel in a boiler in which flue

2   gasses are produced, comprising the steps of:

3   providing a source of fuel;

4   providing a source of air;

5   providing a controller for controlling the ratio of air to fuel fed into

6   said boiler;

7   measuring the oxygen content in the flue gasses;

8   calculating the total amount of air entering said boiler based on the

9   amount of oxygen in the flue gasses; and

1 0   adjusting the air to fuel ratio to include calculated air input and

1 1   measured air input from said source of air;

1 2   whereby the efficiency and NO_x production are improved.

1   2.   The method of claim 1, wherein the air to fuel ratio is adjusted to

2   optimize efficiency.

1   3.   The method of claim 1, wherein the air to fuel ratio is adjusted to

2   minimize NO_x production.

1   4.   The method of claim 1, wherein said fuel is pulverized coal.

1   5.   A system for combustion of fuel in a boiler in which flue gasses are

2   produced, comprising:

3   a source of fuel for combustion in said boiler;

4   a source of air for combustion with said fuel in said boiler;

5   a controller for controlling the ratio of said source of air and said

6   source of fuel inputted into said boiler; and

7   a sensor for measuring the production of oxygen in the flue gasses;

8   said controller being adapted to calculate the total amount of air

9   entering said boiler based on the amount of oxygen the flue gasses to

10 control the air to fuel ratio to include calculated air input and air input

11 from said source of air.

1   6.   The system of claim 5 wherein said fuel is pulverized coal.

1   7.   The system of claim 5 wherein the air to fuel ratio is adjusted to

2   optimize efficiency.

1   8.   The system of claim 5 wherein the air to fuel ratio is adjusted to

2   minimize NO_x production.

1   9.   A system for combustion of fuel in a boiler in which flue gasses are

2   produced, comprising:

3   fuel source means for providing an input of fuel to said boiler for

4   combustion;

5   air source means for providing an input of air to said boiler for

6   combustion with said fuel;

7   controller means for controlling the ratio of said input of air and

8   said input of fuel; and

9   sensor means for measuring the production of oxygen in said flue

10   gasses; said controller means being adapted to calculate the amount of

11   air entering said boiler based on the amount of oxygen the flue gasses to

12   control the air to fuel ratio to include calculated air input and air input

13   from said source of air.

1   10.   The system of claim 9 wherein said fuel is pulverized coal.

1   11.   The system of claim 9 wherein the air to fuel ratio is adjusted to

2   optimize efficiency.

1   12.   The system of claim 9 wherein the air to fuel ratio is adjusted to

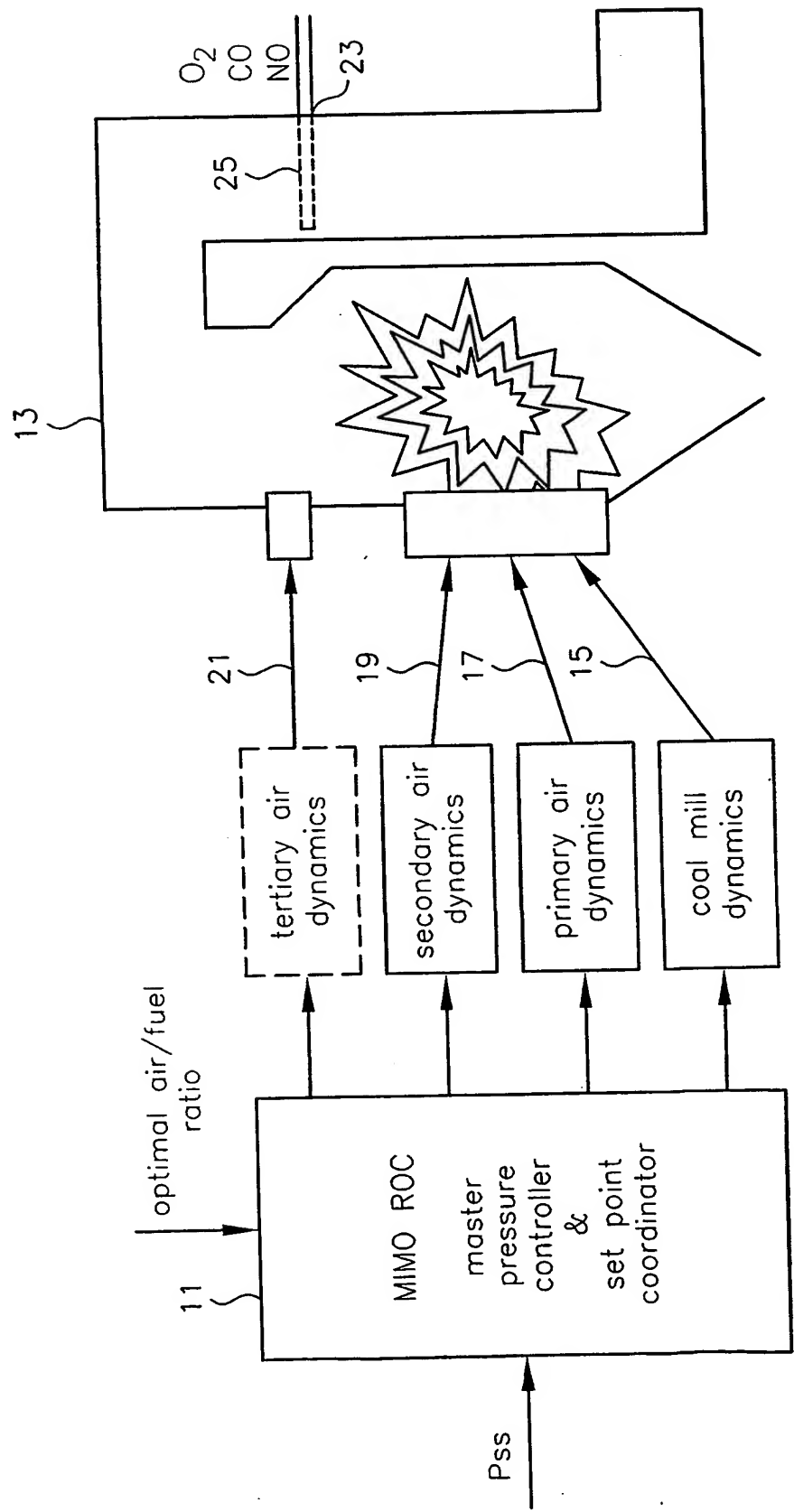2   minimize NO_x production.

Fig-1

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   F23N5/00   F23N1/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   F23N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 007, no. 179 (M-234), 9 August 1983 (1983-08-09) & JP 58 083118 A (HITACHI SEISAKUSHO KK), 18 May 1983 (1983-05-18) abstract; figure	1-12
A	EP 0 773 408 A (HITACHI) 14 May 1997 (1997-05-14) abstract; figures	1,5,9
A	EP 0 519 178 A (MITSUBISHI) 23 December 1992 (1992-12-23) abstract; figures	1,5,9

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 September 2002	10/10/2002

Name and mailing address of the ISA	Authorized officer
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Form PCT/ISA/210 (second sheet) (July 1992)

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